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The development of tritium identification method for the PAMELA experiment

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Abstract

This article focuses on the development of the method of cosmic ray tritium nuclei identification based on data of the PAMELA experiment which is installed on board satellite Resurs-DK1. The tritium nuclei identification was implemented by measuring the particle rigidity and velocity, as well as energy losses in the tracker detectors. We discuss the method of tritium separation on the background of other nuclei. The criteria for event selection allow distinguishing tritium nuclei in the magnetic rigidity range 0.5 – 3.0 GV.

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Keywords: cosmic radiation; tritium; selection criteria

1. Introduction

The galactic cosmic ray tritium nuclei fluxes are of secondary origin only and can be generated as a result of the cosmic ray interactions with atoms of the interstellar medium. As the tritium nuclei are unstable (half-life of 12.3 years), the cosmic ray lifetime in the Galaxy is about $6 \cdot 10^6$ years and the atom density of the interstellar medium is very small, of the order of 0.1 cm^{-3}, so the flux of such generated tritium nuclei in the Galaxy is negligible.

If one considers the albedo fluxes of cosmic rays, the generation of tritium nuclei by the interaction of high energy cosmic rays with atoms of the upper atmosphere could lead to the existence of the albedo fluxes. As the particles interact with atoms of the upper atmosphere at the lower boundary of the inner radiation belt of the Earth,

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this process can be the source of the tritium population of trapped radiation in the vicinity of Earth and this tritium was detected by Looper et al. [1, 2], Bakaldin et al. [3] and Bidoli et al. [4].

Present paper is dedicated to development of identification method for tritium nuclei with energies from 40 to 400 MeV/n in the PAMELA experiment.

PAMELA instrument (Fig. 1) is a magnetic spectrometer, equipped with a time-of-flight system (TOF) and the calorimeter. Short overview of experiment was given by It also includes a shower leakage scintillator detector S_4 and neutron detector located under it. Sensitive spectrometer volume is covered by anticoincidence counters.

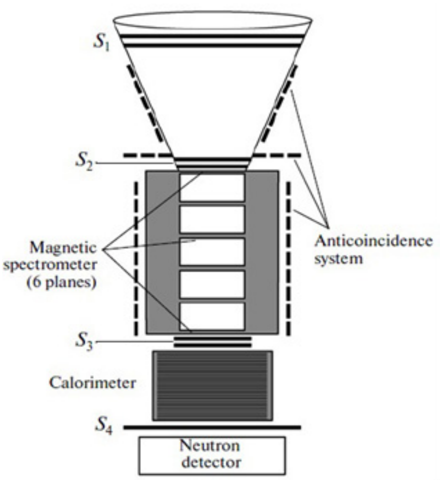

Fig. 1. Scheme of PAMELA instrument.

The permanent magnet creates a magnetic field close to homogeneous, with an average induction of 0.43 T in the workspace with dimensions 13.1×16.1×43.7 cm.

There is "the tracker" in the volume of the magnetic field that is the assembly of the six position-sensitive planes which are thin (300 microns) bilateral microstrip silicon detectors used to measure the coordinates of the particle trajectory in magnetic field and simultaneously the ionization losses in each plane. Accuracy of coordinate measuring is 3.0 μ for the bending view and 12 μ for the perpendicular view. The curvature of the reconstructed trajectory in the magnetic field defines particle magnetic rigidity (the momentum-to-charge ratio).

TOF system consists of three scintillator detectors: S_1 at the top of the device, S_2 over a magnetic spectrometer and S_3 over the calorimeter. Each detector consist of two detection planes divided into bands, bands of adjacent planes being orthogonal. The bands are viewed at their ends by the Hamamatsu R5900 photomultiplier tubes. The thickness of the S_1 and S_3 detectors is 7 mm, of S_2 is 5 mm, the distance between the detectors S_1 and S_3 is 77.3 cm. TOF system is designed to measure the time of particle flight, its time resolution is 250 ps. Each scintillator detector is used to measure the ionization losses of particles passing through them.

Anti-coincidence system allows to exclude from consideration the events when the particle has arrived outside the aperture of the experimental setup.

A more detailed description of the PAMELA experimental instrument, its aims and results can be found in work by Adriani et al [5].

2. The method of tritium nuclei identification

The events available for identification procedure were selected out of the entire set of information recorded in the experiment. This procedure is based on measurements of the magnetic rigidity, velocity and multiple values of energy losses. So the events with correct mentioned above measured values were selected.

Basic selection criteria of “good” events are described in detail in work of Danil’chenko et al. [6].

After the described "basic" selection the identification of nuclei was implemented by analyzing of the diagram constructed in coordinates: average energy losses in the tracker and rigidity (Fig. 2). The values of the energy losses in the diagram are measured in mips. 1 mip correspond to the energy released by minimum ionizing particle passing through the detector.

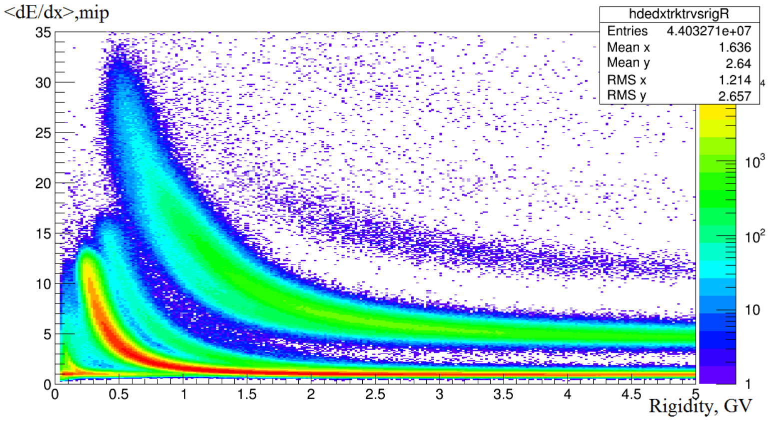

Fig. 2. The diagram “particle magnetic rigidity versus mean energy release in tracker”.

In the diagram one can find the groups of points corresponding to different nuclei, in particular protons, deuterons and helium. But clear identifying of the boundaries corresponding to the area of tritium nuclei is difficult. Tritium area is overlapped with areas of protons, deuterons and He. To correct identifying of tritium nuclei method of suppressing the background of these particles was used. First of all the distribution of particles on the mean energy release in tracker were built for narrow rigidity bands in all range 0.5 – 3.0 GV (Fig. 3).

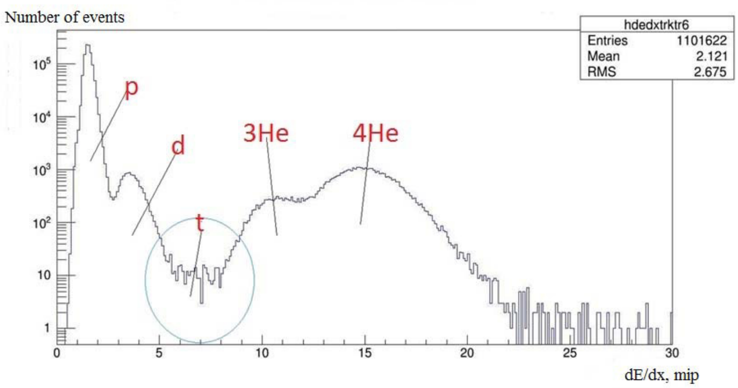

Fig. 3. The event distribution on particle energy release with rigidity 1.0 – 1.1 GV in magnetic spectrometer (tracker).

These histograms were examined for the possibility of area allocating corresponding to an energy release of tritium nuclei. The peaks corresponding to different types of particles are well distinguishable. The areas of these peaks overlap because of the finite tracker energy resolution. The distributions corresponding to hydrogen isotopes overlap as well. Therefore, the precise definition of the number of detected tritium nuclei is almost impossible. Tritium energy losses can be simulated by proton and deuteron ones because of their high intensities with respect to tritium nuclei as well as the background of helium. The same fact is observed in the distribution on value reciprocal to the relative velocity of the particles (Fig. 4).

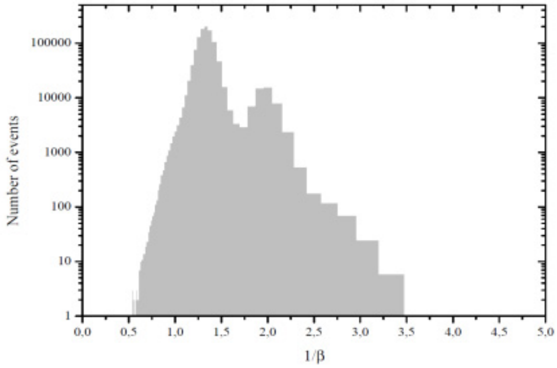

Fig. 4. The event distribution on value of reciprocal particle velocity with rigidity 1.0 – 1.1 GV.

The method developed to suppress the background of p, d and He nuclei was based on multi parametric analysis of data described in details in the work on deuteron identification [6]. The area of tritium nuclei energy release in tracker was limited by two boundary energy release values for each narrow rigidity bands ΔR = 0.1 GV (Fig. 5). The boundary values were chosen to minimize the losses of registered tritium nuclei and to suppress the noise of the other particle in maximum.

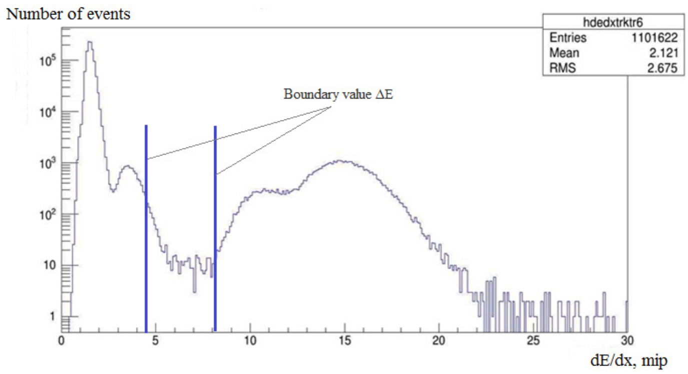

Fig. 5. The distribution of event on mean energy release in tracker ΔE for particles with rigidity 1.0 – 1.1 GV.

Then the new set of events with mean energy losses in tracker confined between the boundaries chosen in previous step was considered. The new distribution was built for reciprocal value of velocity (Fig. 6). One can see that the peaks of tritium nuclei are clearly watched (the area highlighted with a darker color) as well as the vast suppressed background of proton, deuteron and helium events.

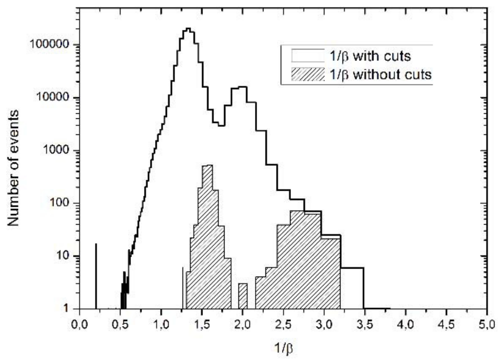

Fig. 6. Distribution on the reciprocal value of velocity for rigidity 1.0 – 1.1 GV.

The coincidence of tritium peak position with the value obtained from the following expression connecting rigidity and velocity:

$$\frac{1}{\beta} = \sqrt{1 + \frac{m^2}{z^2 R^2}} \tag{1}$$

where z is the charge of the particle, m is mass of tritium nucleus and R is the rigidity.
After substituting the values of R = 1 GV, z = 1, m = 2.810 GeV the reciprocal value of particle velocity $1/\beta = 2.86$ was obtained approximately corresponding to the peak maximum in Fig. 6.

Varying the boundary values of energy release in tracker the position of peak value can be obtained as close as possible to value reduced from (1). The search for boundary energy release values $E_{\min}$ and $E_{\max}$ was done for whole studied rigidity range 0.5 – 3.0 GV. The obtained value sets of $E_{\min}$ and $E_{\max}$ were fitted by smart functions. The curves corresponding to these functions were used for separation of tritium nuclei area from other nuclei in all rigidity range (Fig. 7).

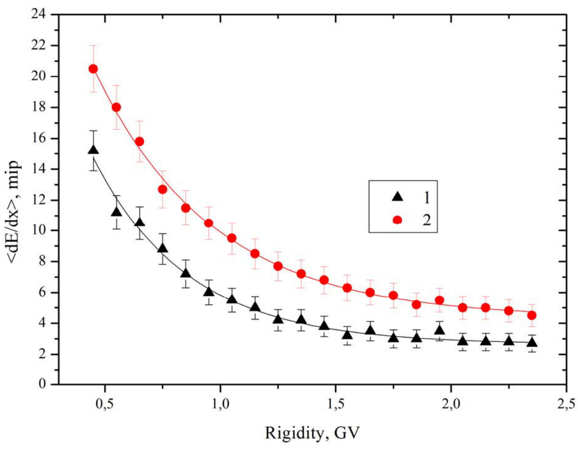

Fig. 7. The dependence of boundary energy releases on rigidity of particles (curves 1 and 2 are corresponded to $E_{\min}$ and $E_{\max}$).

3. Conclusion

As a result the method for selecting the tritium nuclei with rigidity 0.5 – 3.0 GV for PAMELA experiment data was developed. It gave the possibility to separate the tritium nuclei by suppressing the background of hydrogen and helium isotopes.

Counting of the number of tritium nuclei using this method allows to reconstruct the instrument spectrum. For reconstruction of the cosmic ray tritium nuclei spectrum the obtained instrumental spectrum have to be corrected with the use of efficiencies of selection and evaluation of background value.

Acknowledgements

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